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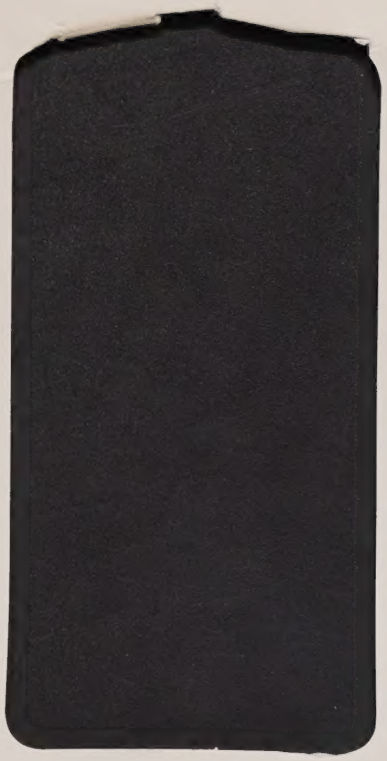
INSTRUCTION MANUAL

MODEL 149

MILLI-MICROVOLTMETER

KEITHLEY INSTRUMENTS



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WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof, except tubes, transistors, fuses, and batteries, which, within a year after shipment to the original buyer, proves defective on examination.

DAMAGE IN SHIPMENT

Be sure to include the instrument model number and serial number in all communications.

If the instrument is damaged when received, or fails to operate properly, a claim should be filed with the carrier. Upon receipt of the claim agent's report, we will inform you regarding repair or replacement.

REPAIRS

When returning an instrument for repair or recalibration, it should be securely packed against shipping damage and sent to the factory, freight prepaid. A brief letter describing the difficulty should accompany the instrument.

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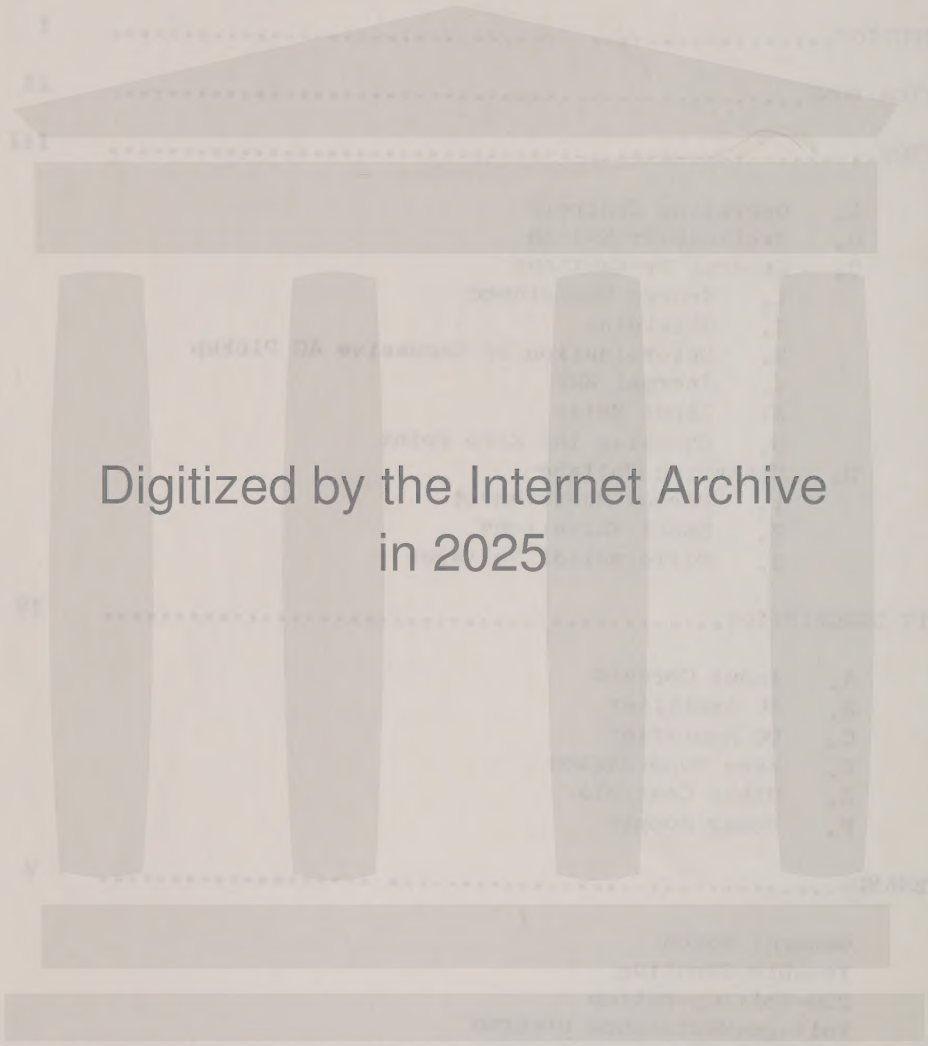

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SECTION I - INTRODUCTION

The Model 149 millimicrovolt meter is a stable, versatile instrument for measuring extremely low level DC signals. It functions as a voltmeter from 100 millimicrovolts to 100 millivolts full scale. It also operates as a DC amplifier with gains up to 10^8 for driving recorders.

The very low noise level of the Model 149, together with its long term stability make it ideal for many measurements requiring extreme power sensitivity.

Typical applications include measuring the output from strain gages, thermopiles, thermocouples, bolometers, phototubes, ionization chambers, scintillation counters, and barrier layer cells. Other applications are found in cell studies, measurement of electrochemical potentials, electrolytic corrosion studies, molecular weight analysis and Hall effect studies.

In addition to its use as a direct indicator of minute potentials and currents, the Model 149 may also be used as a null detector in Wheatstone or Mueller bridges.

An important feature of the instrument is zero suppression up to 100 times full scale, in place of the usual more limited meter zero. This permits measurements of small signals in the presence of large thermal EMF's or other masking DC signals.

SECTION II - SPECIFICATIONS

RANGES: 13 overlapping ranges in 1x and 3x steps from 0.1 microvolts to 100 millivolts on a zero-center meter.

ACCURACY: 2% of full scale on all ranges.

STABILITY: After one hour warm-up within 0.01 microvolts per hour or 0.03 microvolts in any eight hour period with relatively constant ambient temperatures. Drift is noncumulative and will not exceed 1 microvolt during the life of the instrument with source resistances of less than 10K. If high source resistances are used, an additional drift equal to plus or minus 2×10^{-5} R microvolts per eight hours where R is the source impedance should be added to the specification.

NOISE: Input shorted noise is less than 3×10^{-9} volt peak-to-peak (6×10^{-10} volts RMS). At various source impedances the peak-to-peak noise in volts is given by $E = 6.5 \times 10^{-10} (R + 10)^{\frac{1}{2}}$ since the input noise resistance is added to R, the source resistance.

INPUT RESISTANCE, MAXIMUM SOURCE RESISTANCE:

Range Microvolts	Input Resistance Ohms	Max. Source Resistance Ohms
0.1	10K	100
0.3	30K	300
1.0	100K	1000
3.0	300K	3K
10.0	1 meg	10K
30.0	3 meg	30K
100.0 and above	10 meg	100K

RESPONSE SPEED: (10 to 90% of full scale) Depends on source resistance. With maximum specified source resistances less than one second on all ranges except the 0.1 microvolt range where it is within 2 seconds. With source resistances less than 10% of the maximum specified, response is within 0.5 seconds except on the 0.1 microvolt range where it is within 1 second.

ZERO SUPPRESS: Ranges of 1, 10, 100 and 1000 microvolts; and 0.01, 0.1, 1.0 and 10 millivolts corresponding to the position of the function switch. Accuracy of the zero suppression ranges is roughly 20% and stability is such that 100 times full scale may be suppressed.

RECORDER OUTPUT: Plus or minus ten volts at five milliamperes is available from the output terminals.

AMPLIFIER GAIN: The gain as an amplifier varies from a maximum of 10^8 to a minimum of 100 corresponding to range selected.

OUTPUT IMPEDANCE: Less than 100 ohms within the amplifier pass band.

60 CPS REJECTION: Greater than 50:1 on the microvolt ranges.

INPUT ISOLATION: Negative terminal may be grounded or floating up to plus or minus 400 volts with respect to the case. A link is provided for grounding the negative terminal to the case. Impedance to ground floating is greater than 10^9 ohms in parallel with 0.05 microfarads.

TUBE COMPLEMENT: 1-6048, 2-EF86, 2-12AX7, 1-12AT7, 1-6CM6, 1-0A2, 1-12B4A, 1-5651.

POWER REQUIREMENTS: 117/230 volts, 50 watts, 60 cps only; 50 cps models on special order.

DIMENSIONS: 19" wide x 7" high x 13" deep.

NET WEIGHT: 22 lbs.

ACCESSORIES SUPPLIED: Model 1501 low thermal test leads, a length of low thermal solder. Mating output connector.

ACCESSORIES AVAILABLE: Model 1502 Connector Pair, Model 1503 Low Thermal Solder.

SECTION III - OPERATION

A. OPERATING CONTROLS

The controls of the Model 149 are simple and conveniently placed. Their functions are as follows:

ON-OFF switch is located to the right of the panel meter.

FUNCTION switch selects the function which is to be used: Millivolts, or microvolts.

RANGE switch selects the full scale multiplier of the function selected by the FUNCTION switch.

ZERO SUPPRESS controls consists of the ZERO RANGE switch which selects the coarse range of suppressing voltage in discreet steps and the ZERO SET potentiometer which gives continuously variable fine control including settings through zero.

B. PRELIMINARY SET-UP

Connect the instrument to the power line. Unless otherwise marked the unit may be used on 117 volt, 60 cps line. To convert to 220-volt operation, refer to the MAINTENANCE section. A three-wire line cord is furnished, which grounds the cabinet. If a three-wire receptacle is not available, use the two-pin adapter furnished, and ground the third lead to an external ground.

Set controls as follows:

Function: Millivolts

Range: 100

Zero Suppress: OFF

Input: Short the input leads together.

C. GENERAL PRECAUTIONS

1. Source Resistance - In SECTION II - SPECIFICATIONS under INPUT AND SOURCE RESISTANCE, the maximum source resistance for use with each voltage range is specified. Reasonable operation is possible with source resistance up to ten times greater than those specified, however, the measurement will suffer from a considerable decrease in speed of response, and measuring accuracy. If the instrument is left completely open-circuited, the meter will generally drift off scale on any range.

2. Shielding - Since the instrument operates with a modulator frequency of 120 cps, it is not generally sensitive to 60 cps pick-up unless it is large enough to overload the amplifier. The pickup may be a source of difficulty when using the amplifier with high impedances on the more sensitive voltage ranges. In these cases it is desirable to shield the leads and the sources as completely as possible. In some cases a simple low-pass filter at the input to eliminate frequencies of about 1 cps and above will be helpful. No use is made of an input filter in this instrument since any input series impedance due to the filter will increase the input noise and the thermal drift. When operating above ground, the case of the instrument must be grounded.

3. Determination of Excessive AC Pickup - A terminal attached to the output of the AC amplifier at the point of the demodulator is provided at the rear of the instrument. It is labeled DEMOD. OUTPUT. If an inability to make consistent readings persists, it is possible to check for the presence of excessive pick-up by observing the wave-form at this point. With the input shorted the picture should be approximately as shown in figure 1. If excessive pickup is observed it will look as shown in figure 2. The circuit will operate reasonably well as long as the wave-form does not clip as shown in figure 3. At this point the operation will be erratic.

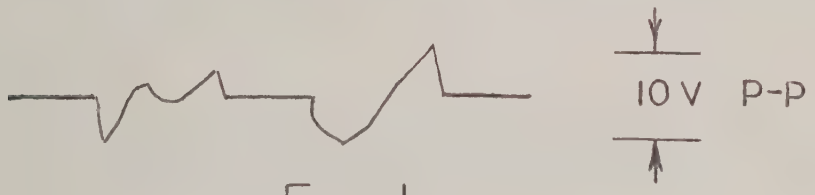


FIG. 1

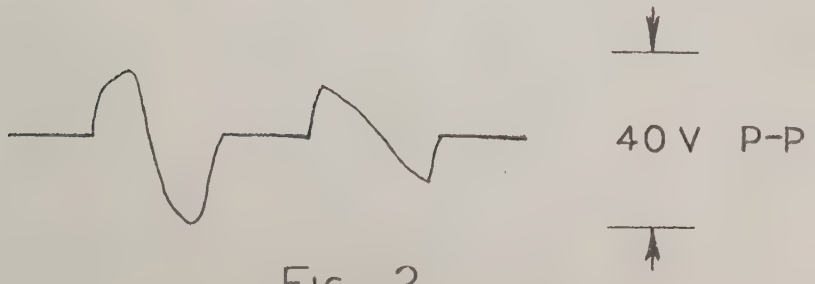


FIG. 2

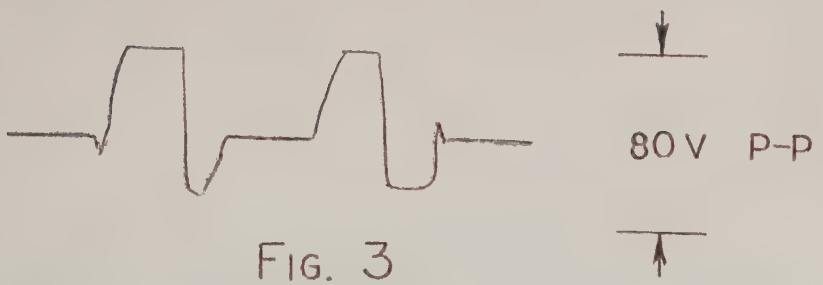


FIG. 3

4. Thermal EMF - Extreme precautions have been taken in the input circuit to minimize thermal EMF's so the residual EMF is usually less than 0.2 uv. The material used in the input circuit is pure copper. Any other metal will generate a thermocouple potential. Lead solder is particularly troublesome. Where thermal EMF's are supplied with the instrument.

5. Input Noise: The noise at the input is a function of input resistance and is approximately given by

$$E = 1.29 \times 10^{-10} (R+10)^{\frac{1}{2}}$$

where E is the RMS noise, and R is the source resistance. It is assumed that the bandwidth of the instrument is about 1 cps and the temperature is 80° F. If noise is observed, calculate the theoretical noise and compare results. Also bear in mind that only wire-wound resistors approach the ideal resistor. However, if Evanohm or manganin resistors are used, a considerable thermal EMF of the resistor material against copper will be observed.

6. Checking the Zero Point - At low levels, spurious EMF's may be generated simply by contact between the input leads and the terminals under test. If possible, always leave the instrument connected and adjust the zero after establishing a zero reference in the apparatus under test. For example, in bridge measurements, disconnect the bridge exciting voltage; or with a phototube, shield the tube from light.

D. MEASURING VOLTAGE

1. Direct Voltage Measurements - Place the FUNCTION switch at MILLIVOLTS or MICROVOLTS as necessary for the measurement to be taken. Then turn the RANGE switch to more sensitive ranges until the meter gives a usable deflection.

2. Measuring Voltage Variations - To observe small variations in a large steady signal first set the FUNCTION and RANGE switches as described in D 1. Then operate the ZERO SUPPRESS switch and potentiometer to reduce the meter deflection to zero. Increase the meter sensitivity with the range switch. The stability of the suppression voltage is adequate for 100 x full scale suppression. Thus, if a thermocouple is suppling a signal of 10 millivolts to the Model 149 after suppressing the meter deflection to zero the RANGE may set at 100 microvolts. If the 10 millivolt signal corresponds to a temperature of 250°C then after suppression variations of 2.5°C are seen full-scale.

3. Measuring Differential Voltages - When measurements are to be made in a circuit where the LOW connection is above ground potential, slide OUTPUT LINK from one of its posts. This disconnects the instrument circuit ground from chassis ground. DO NOT attempt to make such measurements where the low side of the circuit being measured is more than 400 volts above external ground potential.

If a recorder is being used with the instrument in this arrangement, the recorder must not be grounded since the low side of the output is no longer being grounded.

E. OTHER APPLICATIONS

1. Null Indicator - The Model 149 makes an extremely sensitive null indicator which may be used in a wheatstone or Mueller Bridge.

If the bridge is arranged so that one terminal of the detector is grounded, the Model 149 may be used as described in D 1. If the detector must be used floating, remove the DISCONNECT LINK at the rear and observe the same precautions as in D 3.

SECTION IV - CIRCUIT DESCRIPTION

The Model 149 is basically a narrow-band chopper amplifier employing negative feedback to stabilize the gain and increase the input impedance.

A. Input Circuit

Zero Stability: The effect of thermal EMF's generated in the input circuitry is reduced to nearly the vanishing point by the use of only copper in the input circuit. All solder points are made with a low thermal cadmium-tin solder. The chopper and chopper transformer employ copper leads. All switching in the input circuit is accomplished with copper switch. Critical resistors in the input circuit are wound of copper wire. The input connector has solid copper spring-loaded contacts.

The input voltage is applied to the moving arm of a 120 cps mechanical chopper. The feedback voltage is connected to the primary center tap of the input transformer. Thus, the difference voltage is applied first across one half of the primary and then, with phase reversal, to the other half. This full wave error signal is stepped up 90 to 1 by the input transformer and applied to the grid of V1, a 6084 low-noise pentode.

B. AC Amplifier

In parallel with the plate load resistor of V1 is a relatively high Q, 120 cps resonant circuit which narrows the bandwidth and reduces spurious signals.

V2 and V3, EF86 pentodes, further amplify the chopper error signal which is then demodulated synchronously by silicon diodes D1 through D4.

To obtain the 120 cps demodulator driving signal, use is made of the ripple frequency from a bridge rectifier circuit operating from the line voltage. The ripple is used in the primary of the demodulator driver transformer.

C. DC Amplifier

The demodulated signal is applied to the grid of V4. V4, V5, and V6 form the dc amplifier and output cathode follower which add further forward gain to the system and supply output power. Feedback around V4, V5 and V6 multiplies the effective capacitance of demodulator filter capacitor C113 by about 1000. This yields the large equivalent capacitance necessary to smooth the demodulated error signal. Because of the feedback, spurious noise in the dc stages outside the pass band of the whole amplifier are effectively degenerated.

D. Zero Suppression

A low-current ±10 volt supply is derived from the main dc supplies using 10-volt zener diodes. Potentiometer R174 may be set at any voltage from -10 to +10 volts, this voltage is applied through appropriate dropping resistors to the feedback point to achieve zero suppression. The potentiometer is the front panel control marked ZERO SET, while switch SW3, which determines the portion feedback, is labeled ZERO RANGE.

E. Other Controls

Two controls are set at the factory and should require only infrequent attention by the user.

R118 is an internal control marked DC AMP BAL. It is used to zero the DC amplifier, i.e., to set the output voltage to zero when the demodulator output is zero. This is not very critical since an unbalance will simply be fed back to the input to produce a small error signal to correct itself. R127 is marked CAL. This is the variable portion of the meter multiplier resistance to allow for meter-to-meter sensitivity differences.

F. Power Supply

A standard half-wave rectifier followed by an R-C filter is used to supply unregulated B+ and B- to the output cathode follower.

The unregulated B- is regulated to -150 volts in V7, OA2, and is used for the negative returns for the dc amplifier.

Unregulated B+ is fed to the plate of V8, 12B4A, the series tube in a 225-volt electronic regulator. The output voltage from this regulator is divided by R510 and R511 and compared to reference tube V9, a 5651. The difference signal is amplified by cascode amplifier V10, a 12AX7, and applied to the grid-cathode circuit of the series tube. This regulated 225 volts supplies B+ directly to the dc amplifier, through a decoupling filter (R176, C110) to the second and third ac amplifier stages, and through another decoupling filter (R103, C104) to the first ac amplifier stage.

Regulated B+ and B- also supply currents to the 10 volt zener diodes which are used for zero suppression. This gives two-stage regulation for these very critical voltages.

Zener Diode DZ1 regulates the filament voltage of V1 to reduce line transient effects.

SECTION V - MAINTENANCE

Except for occasional tube or chopper replacement, very little maintenance is required by the Model 149. Components are operated well below rating and solid-state devices are employed where possible to achieve long, trouble-free service.

Certain portions of the input circuit are wired using copper wire and special cadmium-tin solder. These special joints are painted red. If, for any reason, these joints must be unsoldered or re-soldered, USE ONLY CADMIUM-TIN SOLDER AND A COPPER-TIPPED SOLDERING IRON WHICH HAS NEVER BEEN USED WITH ORDINARY LEAD-TIN SOLDER. A small spool of cadmium-tin solder is supplied with each instrument.

What may seem to be circuit failure in the millimicrovoltmeter is quite often found to be an unusual condition in the entire test set-up. Therefore, before trouble-shooting the instrument, check to see whether it operates correctly with:

1. All other circuitry disconnected.
2. Input shorted (with copper leads).
3. Power line voltage and frequency correct.

If the difficulty persists, the following systematic procedure may be employed to determine the fault.

TROUBLE-SHOOTING

Reference is made to the Schematic Diagram 13621D, and the Voltage-Resistance Diagram enclosed at the rear of the manual.

To begin trouble-shooting, short the input terminals, strap G to LO with the link provided, and switch ZERO RANGE to OFF. A Zero offset of a 0.1 to 0.4 of a microvolt is normal.

EXCESSIVE OUTPUT NOISE (INPUT TERMINALS SHORTED)

Unfortunately, because of the very low signal levels involved, noise in the ac amplifier is difficult to trace by other than the substitution method. Most logical noise sources are V1 or the chopper. To replace the chopper, unplug the cap at the top, and unsolder the chopper leads. USE ONLY low thermal solder and new copper tipped iron tinned with low thermal solder!!! Unscrew the two chopper mounting screws and lift out the chopper. When inserting the new chopper, make sure that the chopper leads are soldered securely with low-thermal solder. Observe color-coding on the leads. If the noise persists, the noise is being generated in the dc amplifier or power supply. A stage-by-stage search should reveal the source. Very often the noise is generated by R102, low noise metal film resistor. Replace only with a direct equivalent. Wire wound resistors tend to introduce inductive pickup.

OUTPUT NOT ZERO (WITHIN 0.5 MICROVOLT) WITH INPUT TERMINALS SHORTED

Be sure than ZERO RANGE is set to OFF. Short the dc amplifier input grid, pin 7 of V4, to ground. Use the DC AMP BAL control to set the output to zero. The control will become very "scratchy" but the adjustment is possible. If this cannot be done, the dc amplifier or power supply are at fault. If it can be set to zero, the trouble may be in the ac amplifier or demodulator circuit.

a. Power Supply - B + should be about + 225 on pin 1 of V8, and B- should be -150 on pins 2, 4 or 7 of V7. If V7 is not firing, correct the fault in the unregulated B-. If + 225 is not present, check for unregulated B + (about 340 volts) at the plate pin 9 of V8. If the unregulated B + is all right, check the tube pin voltages of V8, V9, and V10 to locate the faulty tube or part.

b. AC Amplifier - Remove the output tube (V6) and clip pin 1 of the output connector to ground. Place the FUNCTION switch on MILLIVOLTS, and turn the ZERO SET and ZERO RANGE controls full clockwise. This puts a large dc error signal across the chopper and input transformer. Use an oscilloscope to check for the presence of 120 cps at the primary of the input transformers (the two outside terminals on the chopper terminal block). Absence of signal means chopper failure (or much less likely, a shorted or open input transformer). Listen for audible chopper action and check chopper drive, if necessary.

If the 120 cps signal is present, check stage-by-stage throughout the ac amplifier, reducing the input signal as desired by backing off the ZERO RANGE and/or ZERO SET controls, until the failure is discovered.

d. Demodulator Circuit - Check for presence of about 80 volts RMS at the secondary of the demodulator transformer (at the ends of R113 and R114).

The tests outlined above will not suffice to pin-point every fault which may exist. They should, however, lead to the correction of common failures. In the event that troubles cannot be corrected by these means, or the user finds it more expedient, the unit may be returned to the factory for repair and recalibration at a nominal cost.

220-VOLT OPERATION

For 220- volt operation the power transformer primary connections must be changed. The jumpers connecting black and black-white together and blue and blue-white should be removed. The blue and black-white leads should be tied together.

REPLACEABLE PARTS LIST - MODEL 149

Circuit Des.	Description	Part No.
C-102	Capacitor, Tubular Electrolytic, 15 VDCW - 5 MFD	C11-5
C-103	Capacitor, Metalized Paper, 200 VDCW - 0.1 MFD	C18-.1
C-104	Capacitor, Tubular Electrolytic, 450 VDCW - 20 MFD	C8-20L
C-105	Capacitor, Mylar Dielectric, 400 VDCW - .1 MFD	C30-.1
C-106	Capacitor, Mylar Dielectric, 100 VDCW - .0082 MFD	C45-.0082
C-107	Capacitor, Same as C-102	
C-108	Capacitor, Ceramic Disc. 600 VDCW - .01 MFD	C22-.01
C-109	Capacitor, Same as C-103	
C-110	Capacitor, Same as C-104	
C-111	Capacitor, Same as C-102	
C-112	Capacitor, Same as C-105	
C-113	Capacitor, Mylar Dielectric, 200 VDCW - .47 MFD	C29-.47
C-114	Capacitor, Ceramic Disc. 600 VDCW - .001 MFD	C22-.001
C-115	Capacitor, Ceramic Disc. 600 VDCW - .0047 MFD	C22-.0047
C-116	Capacitor, Same as C114	
C-501	Capacitor, Tubular, Electrolytic, 600 VDCW -20 MFD	C35-20
C-502	Capacitor, Same as C-104	
C-503	Capacitor, Same as C-501	
C-504	Capacitor, Same as C-108	
C-505	Capacitor, Same as C-104	
C-506	Capacitor, Mylar Dielectric, 600 VDCW, .05 MFD	C62-.05
C-507	Capacitor, Tubular Electrolytic, 12 VDCW, 1000 MFD	C11-1000
C-509	Capacitor, Same as C-105	
L-1	Choke, 200 HY., 120 CPS - HI. Q.	CH-1
J-1	Connector, Input; Special	13752-B
J-2	Connector, Demodulator Jack	CS-65
J-3	Connector, Output; Amphenol, 80 PC 2F	CS-32
CHOPPER	Frequency Doubling, Special 60 Cycle	CV-2
	50 Cycle	CV-3
D-1	Diode, Silicon - In 2069	RF-20
D-2	Diode, Silicon - Same as D-1	
D-3	Diode, Silicon - Same as D-1	
D-4	Diode, Silicon - Same as D-1	
D-5	Rectifier, Selenium	RF-18
D-6	Rectifier, Selenium	RF-18
D-7	Rectifier, Selenium	RF-18
D-8	Rectifier, Selenium	RF-18
D-9	Rectifier, Selenium	RF-18
D-10	Rectifier, Selenium	RF-18
D-11	Rectifier, Bridge	RF-7
D-12	Diode, Zener	DZ-4
D-13	Diode, Zener	DZ-ZA10
D-14	Diode, Zener	DZ-ZA10

REPLACEABLE PARTS LIST - MODEL 149

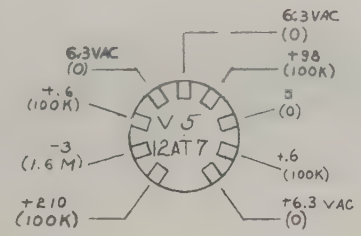
Circuit Desig.	Description	Part No.
R-101	Resistor, Composition: 10%, ½ watt, 33K	R1-33K
R-102	Resistor, Metal Film: 1%, 1 watt, 2M	R44-2M
R-103	Resistor, Composition: 10%, ½ watt - 47K	R1-47K
R-104	Resistor, Dep. Carbon: 1% ½ watt - 1 Meg.	R12-1M
R-105	Resistor, Composition: 10% ½ watt - 3.3 Meg.	R1-3.3M
R-106	Resistor, Same as R-104	
R-107	Resistor, Composition: 10%, ½ watt - 22K	R1-22K
R-108	Resistor, Same as R-105	
R-109	Resistor, Same as R-104	
R-110	Resistor, Same as R-107	
R-111	Resistor, Same as R-104	
R-112	Resistor, Deposited Carbon: 1%, ½ watt - 200K	R12-200K
R-113	Resistor, Deposited Carbon: 1%, ½ watt - 100K	R12-100K
R-114	Resistor, Same as R-113	
R-115	Resistor, Deposited Carbon: 1%, ½ watt - 1.2 Meg	R12-2M
R-116	Resistor, Deposited Carbon: 1%, ½ watt - 470K	R12-470K
R-117	Resistor, Deposited Carbon: 1%, ½ watt - 333K	R12-333K
R-118	Potentiometer, 500K Ohms	RP5-500K
R-119	Resistor, Deposited Carbon: 1%, ½ watt - 680K	R12-680K
R-120	Resistor, Deposited Carbon: 1%, ½ watt - 3.33M	R12-3.33M
R-121	Resistor, Deposited Carbon, 1%, ½ watt - 2.2 Meg.	R12-2.2M
R-122	Resistor, Deposited Carbon, 1%, ½ watt - 60K	R12-60K
R-123	Resistor, Same as R-113	
R-124	Resistor, Same as R-104	
R-125	Resistor, Same as R-104	
R-126	Resistor, Wirewound: 5%, 10 watt - 30K	R5-30K
R-127	Potentiometer, 10K Ohms - Wire Wound	RP9-10K
R-128	Resistor, Deposited Carbon, 1%, ½ watt. - 96K	R12-96K
R-129	Resistor, Special; Copper Wirewound, 1 Ohm, .5%MATCH.	14176-A
R-130	Resistor, Special; Copper Wirewound, 1K Ohm .5%PAIR	
R-131	Resistor, Deposited Carbon, Special: 1%, ½W. 110 Ohms	R38-110
R-132	Resistor, Copper Wirewound, Special: 5%, 10K Ohms	R18-19-10K
R-133	Resistor, Deposited Carbon, Special: 10%, ½W 100K	R38-100K
R-134	Resistor, Deposited Carbon, 1%, ½ watt - 10M	R12-10M
R-135	Resistor, Deposited Carbon, 1%, ½ watt - 3.33M	R12-3.33M
R-136	Resistor, Same as R-104	
R-137	Resistor, Deposited Carbon, 1%, ½ watt - 333K	R12-333K
R-138	Resistor, Deposited Carbon, 1%, ½ watt - 100K	R12-100K
R-139	Resistor, Deposited Carbon, 1%, ½ watt - 32.3K	R12-32.3K
R-140	Resistor, Deposited Carbon, 1%, ½ watt - 10K	R12-10K

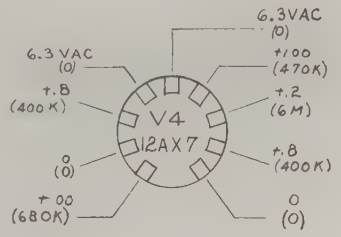
REPLACEABLE PARTS LIST - MODEL 149

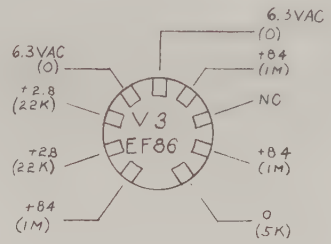
Circuit Desig.	Description	Part No.
R-141	Resistor, Composition; 10%, ½ watt - 470K	R1-470K
R-142	Resistor, Same as R-133	
R-143	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-144	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-145	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-146	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-147	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-148	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-149	Resistor, Composition; 10%, ½ watt - Value Chosen to Prevent Oscillatio	
R-150	Resistor, Deposited Carbon; 1%, ½ watt - 1K	R12-1K
R-151	Resistor, Same as R-104	
R-152	Resistor, Same as R-113	
R-153	Resistor, Same as R-140	
R-154	Potentiometer, 10-Turn, 10K	RP4-10K
R-155	Resistor, Wire Wound; 5%, 10 watt - 30K	R5-30K
R-501	Resistor, Composition, 10%, 1 watt - 100	R3-100
R-502	Resistor, Same as R-501	
R-503	Resistor, Wirewound, 5%, 10 watt - 5K	R5-5K
R-504	Resistor, Same as R-503	
R-505	Resistor, Composition, 10%, 1 watt - 22K	R3-22K
R-506	Resistor, Composition, 10%, ½ watt - 10M	R1-10M
R-507	Resistor, Deposited Carbon, 1%, ½ watt - 220K	R12-220K
R-508	Resistor, Composition, 10%, ½ watt - 33K	R1-33K
R-509	Resistor, Same as R-508	
R-510	Resistor, Composition, 10%, ½ watt - 1M	R1-1M
R-511	Resistor, Deposited Carbon; 1%, ½ watt - 600K	R12-600K
R-512	Resistor, Wire Wound; 5%, 10 watt - 10 Ohm	R5A-10
S-1	Switch, Function - Special — Rear Section	13728-B
	Front Section	14090-A
S-2	Switch, Range	SW-96
S-3	Switch, Zero Range	SW-58
S-4	Switch, On-Off	SW-14
T-1	Transformer, Power-Central Transformer, K1-162	TR-36
T-2	Transformer, Demodulator-Central Transformer, K1-147	TR-26
T-3	Transformer, Input - Triad G 40549	TR-37
M	Meter	ME-14

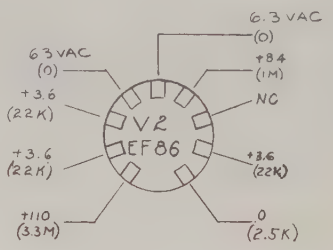
REPLACEABLE PARTS LIST - MODEL 149

Circuit Desig.	Description	Part No.
V-1	Tube, Vacuum - 6084	EV-6084
V-2,V-3	Tube, Vacuum - EF 86	EV-EF86/6267
V-4,V-10	Tube, Vacuum - 12AX7	EV-ECC83/12AX7
V-5	Tube, Vacuum - 12AT7	EV-12AT7
V-6	Tube, Vacuum - 6CM6	EV-6CM6
V-7	Tube, Vacuum - OA2	EV-OA2
V-8	Tube, Vacuum - 12B4A	Ev-12B4A
V-9	Tube, Vacuum - CK5651	EV-CK5651

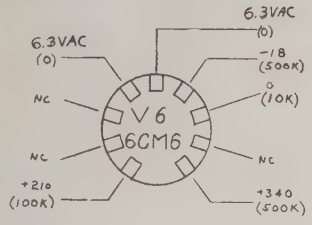


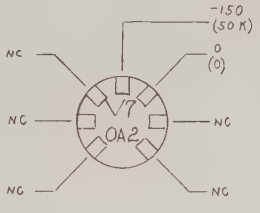


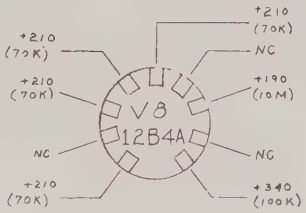


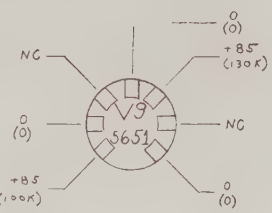


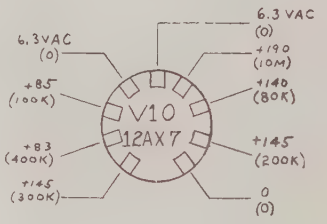
PC-22







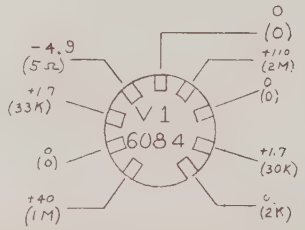




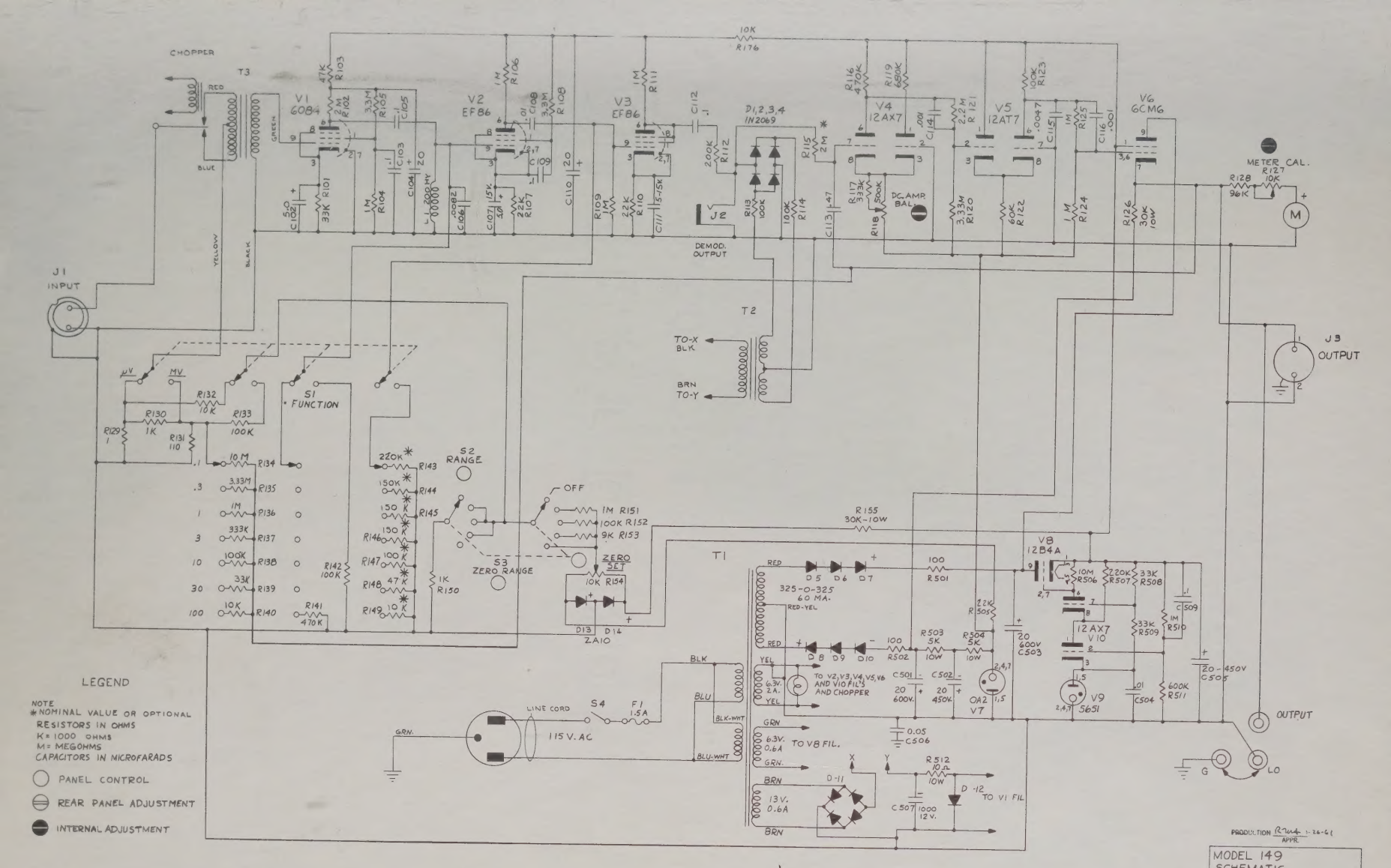
MODEL 149
VOLTAGE AND RESISTANCE CHART

MEASUREMENTS FROM TUBE PIN TO GROUND USING VTVM WITH 10 MEGOHM INPUT RESISTANCE. FUNCTION SWITCH AT MILLIVOLTS, INPUT SHORTED, RANGE SWITCH AT 1000, ZERO SUPPRESS OFF.

ALL READINGS ARE APPROXIMATE:
RESISTANCES ARE GIVEN IN OHMS; K=1000; M=MEGOHMS



KEITHLEY INSTRUMENTS
DR 13745C

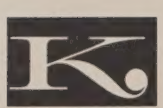


PRODUCTION RWA 1-26-61
APPR.

MODEL 149
SCHEMATIC

KEITHLEY INSTRUMENTS
CLEVELAND, OHIO

DR	DATE	CH	DATE	DR13621-D
RAK	7-1-60			



KEITHLEY INSTRUMENTS, INC.
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